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Daly, J., Armstrong, E., Thomson, E., & Martin, S. (2014). A Brain Computer Interface for eInclusion and eHealth. In P. Cunningham, & M. Cunningham (Eds.), *Unknown Host Publication* International Information Management Corporation. <http://www.echallenges.org/e2014/>

[Link to publication record in Ulster University Research Portal](#)

Published in:
Unknown Host Publication

Publication Status:
Published (in print/issue): 29/10/2014

Document Version
Author Accepted version

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A Brain Computer Interface for eInclusion and eHealth

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Abstract: Brain Computer Interfaces enable people with disability to access computer technology, when traditional modes are beyond their ability. This novel technology, uses brain waves to initiate the software, enabling people with acquired brain injury (ABI) to access applications for eHealth and eInclusion. This paper reports on the outcome of research with target end users and a control population to develop applications for communication, cognitive rehabilitation, social media and environmental control. Adopting a user centred approach we found that the control group achieved an average accuracy of 82.6% and end users achieved 74% over the four tasks. The findings illustrated that BCI systems are operational for users with ABI and numerous recommendations were made to support developer's move these systems towards use in a domestic environment.

1. Introduction

An Acquired Brain Injury (ABI) is sudden damage to the brain due to illness or injury. It is estimated that 3.7 million people are living with an ABI in Europe [1] and the number affected is expected to rise considerably due to improvements in healthcare and the extension of life expectancy [2]. The impact of the injury can vary depending on the severity from complete recovery to 'locked in syndrome'. A person with locked in syndrome can be completely paralysed, although some people may have residual movement of eyes and/or certain facial muscles, it is difficult or impossible to communicate. Long-term ABI problems include physical disability, cognitive impairment, communication difficulties, inappropriate behaviour, restricted independence, social isolation and poor quality of life. ABI is correlated with a significant cost burden due to hospitalisation, rehabilitation, assistive technology, and long-term dependency on healthcare services [3].

Assistive technologies aim to increase quality of life [4], reduce dependence on caregivers [5] and reduce reliance on the long-term care system [6]. Brain Computer Interfaces (BCI) are novel systems that enable people to communicate and control their environment without any muscle activity. BCI harness brainwaves through non-invasive electrodes placed on the skull to enable users with severe disabilities to interact with computer systems and their services [7]. The adoption of BCI offers the unique opportunity for people with ABI to regain control over their lives and access tools and services that support eInclusion, eParticipation and eAccessibility, through the trajectory of disability [8]. Additionally, developers of BCI systems are working to enhance access to health care, rehabilitation and eHealth to support the transition from hospital to home following an ABI [9].

BCI systems are inherently complex in terms of hardware, software and functionality to provide a range of services. The challenge is how to develop systems and services that are

useful, reliable and accessible to people with ABI. Although BCI can control a number of applications little research has taken place with the target user group ie people with acquired brain injury [10] [11]. To date research has tended to focus on the detection of performance speed, bit rates and accuracy [12] however usability and end user requirements are equally if not more important in the development of the BCI [13]. To maximize the likelihood that these systems will be adopted and used at home on a daily basis it is essential to work closely with people who will benefit from such systems.

This research is pan-European and involves people with ABI and those without, as a control group in the design and evaluation of a BCI system employing user-centered design (UCD) principles [14] [15] [16]. A UCD approach centers on engaging directly with people that could potentially benefit from a product to identify their specific requirements and to test the systems usability in terms of effectiveness, efficiency and satisfaction. A number of studies have incorporated this approach successfully in the evaluation of BCI for long-term home use [15] [17] [18] [19]. The present paper presents the results of an UCD evaluation of a BCI prototype that has developed applications to enhance eHealth and eInclusion for users with ABI in their home environment.

2. Objectives

To identify the usability and user satisfaction in a BCI system with target end users and a control population, exploring a range of applications to enable eInclusion and eHealth.

3. Methodology

An experimental study with a purposive sample of a control group of people who do not have ABI and an intervention group of people with ABI was designed and completed. The study included a protocol to use when operating the BCI system, combined with quantitative tools and qualitative interviews. Ten people were recruited to evaluate the prototype. First, five participants (4 female, $M = 36.6$ years, ± 9.3) in the control group were recruited for the evaluation. Once the first phase of testing was complete, five target end users (1 female, $M = 37$ years, ± 8.7) who are living with ABI (Post ABI $M = 9.8$ yrs, ± 3.7) were recruited.

The testing phase for prototype two required each participant to complete an extensive 40-step protocol on three occasions each. The researcher guided the participants through the process, which included spelling the word 'BRAINPOWER', completing two cognitive rehabilitation tasks (Figure 1), tweeting '#BCI #BACKHOME' and smart home control that involved moving a camera application in three different directions. Participants were invited to complete two additional 15-step tasks on one occasion each. The first was to operate a multimedia player and the second task was to paint a picture using an application called Brain Painting.

For the prototype evaluation, participants aimed to complete the protocol on three occasions, followed by the VAS (visual analogue scale) questionnaire to rate overall satisfaction. After each final evaluation session participants completed the extended QUEST 2.0 (Quebec User Evaluation of Satisfaction with Assistive Technology: [20]), a customized usability questionnaire and the NASA-TLX (NASA-Task Load Index: [21]) to assess workload. Ethical approval was granted by the University of Ulster.

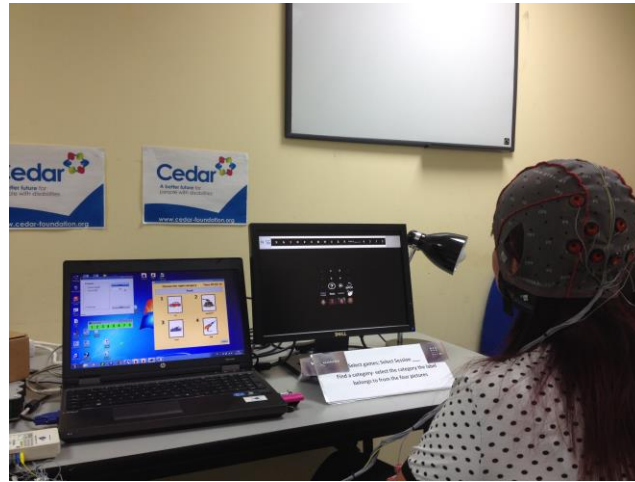


Figure 1: Participant completing the Find a Category Cognitive Rehabilitation Task

4. Technology Description

The BCI system used a P300 based paradigm that was placed next to the user interface. The user interface was placed approximately a meter in front of the participant to enable control of applications. The EEG was acquired using an electrode cap with 8 active Ag/AgCl electrodes (g.Gamma, g.tec Austria), at electrode Fz, Cz, P3, POz, P4, PO7, Oz, PO8. Channels were referenced to the right earlobe and a ground electrode was placed at FPz and the signals were amplified by a g.USBamp (g.tec Austria). The classifier was created during the training sessions when the user was required to select five letters from the 6 X 6 matrix. A selection could be made when the participant attends to their target symbol and mentally count the amount of times it flashed as the rows and columns flashed at random. Once the classifier was created users were then asked to complete the protocol on the system.

5. Results

All participants were able to complete the protocol in full on three separate sessions. Participants were enthusiastic with the range of applications and the systems' responsiveness. The same protocol was completed by both groups, however the control participants completed the protocol without stopping and the prototype was stopped after each task for the end user group. This enabled the end users to have a break and this also seemed to prevent the prototype from crashing as it did for the control group.

The control group recorded an average accuracy of 82.6% (± 4.7) following completion of the full protocol on three occasions. The cognitive rehabilitation tasks were the most responsive for the control group while the camera task reported the lowest accuracy score of 52.73% ± 11.97 . Figure 2 contains the average accuracies for each of the tasks.

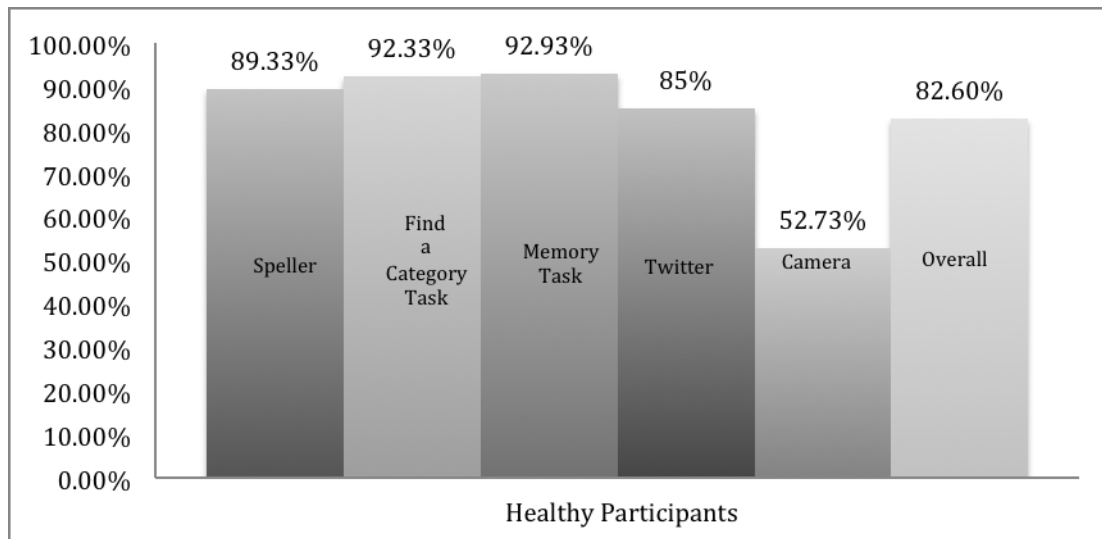
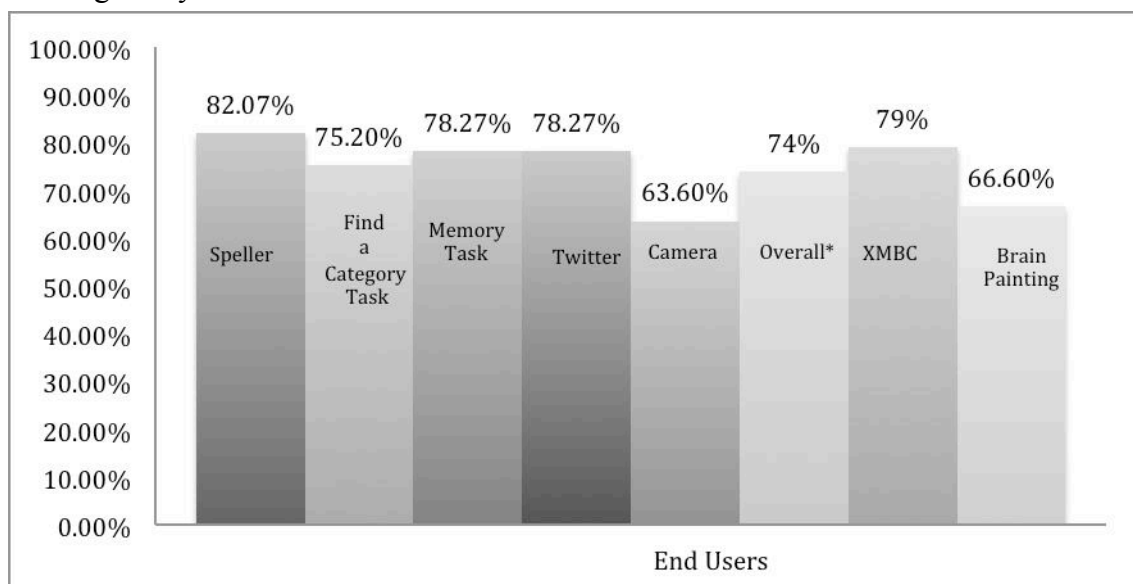


Figure 2: Control Group Average Accuracy Scores for Each Application

The average accuracy for the complete protocol inclusive of the four applications was 76.13% (± 11.51). The highest overall accuracy was achieved with the Speller (82.07% ± 13.34) and the lowest was the camera task (63.6% ± 22.8). Figure 3 contains the average accuracies for each of the tasks. The difference in the camera task accuracy scores between groups could be attributed to a system stability issue. Within the control group evaluation the system crashed when the users were trying to select the ‘smart home’ icon from the bottom of the opening matrix (control group= 50% / end users= 71%) in the majority of sessions, whilst this was no longer an issue during the end user testing because of stopping and starting the system between tasks.



* Overall Average Accuracies is calculated by the five tasks completed over the three sessions. XMBC and Brain Painting Tasks were only completed once.

Figure 3: End Users Average Accuracy Scores for Each Application

The subjective workload using the NASA TLX was reported as moderate to high workload (57.10 ± 10.9) for the control group and moderate workload for end users (41.42 ± 23.5). The end users overall device satisfaction reported on the VAS was 7.64 (± 1.78) and ranged from 9.3 to 6.9 individually on average over the three sessions. The control group indicated on the VAS (VAS=6.57 ± 1.2) that they were not as satisfied as End users with the overall device on day-to-day basis. The average QUEST score for the control group was

4.35 (± 0.5) (4= quite satisfied) and the QUEST Added Items average was 4.24 (± 0.5). The average QUEST score for end users was 3.86 (± 0.6) (4= quite satisfied/ 3= more or less satisfied) and the QUEST Added Items average was 3.58 (± 1.1). The QUEST items rated as most important were: Ease of Use (6); Effectiveness (5); Speed (5); Reliability (5); Comfort (4).

The evaluation found that the system does work for people with acquired brain injury but that the prototype requires further refinement if it is to be used at home on a daily basis.

Recommendations included:

- Reduced complexity of the set up and signal acquisition
- Better system reliability so that is more stable and does not crash when the user is interacting with it
- Option to customize the speed of the cognitive rehabilitation application to give end users time to decide on their answer (or a pause/resume button) Web browser and Twitter letter selections made more distinguishable
- The system should not make its own selections when the participant is attending the desktop screen (i.e. watching a video) to stop it changing the page or the application.
- The application should come to the front of the desktop screen when it is selected by the user on BCI otherwise the system can't be used independently
- A simple reference guide for end users to interpret all of the individual applications and the meaning of symbols on the user interface should be created
- Increased response rate and accuracy within all applications especially the Camera task

6. Business Benefits

The current challenge for BCI research is moving the system towards commercially available devices that can be used at home by people who could benefit from the technology. This research indicates that the current BCI is not yet ready to be a marketable product however the findings can contribute to the knowledge base aimed at moving systems closer to this aspiration. Key lessons included the importance of engaging with end users given the variation of results between the control group and the end user group. Kubler et al (16) outlined this approach as fundamental in bridging the gap in the research from the laboratory to domestic home use. End users stated the importance of navigating the system easily, independently and to have a degree of personalisation available in order to become truly independent and access the eHealth and eInclusion applications.

Additional problems encountered included the complexity of the BCI hardware, the software and set up of the system. This research provides specific recommendations to the developers to reduce this and so enable the caregiver to set up the system independently in a way that does not add additional constraints to their daily routine. Advancements in the design and development of the electrode cap are key to enable the signal acquisition become easier and to improve the aesthetic design. Therefore a number of hardware and software amendments are being considered to increase user acceptance and the usability of the system.

The current prototype sought to enable the user to access a range of eHealth and eInclusion services. The ambition of a future iterative of the prototype is to have a platform on which these services can be offered to support the transition for people with ABI from hospital to home, to increase therapeutic outcomes through a telemonitoring system [9], and to enable communication, entertainment and environmental control [8][10]. The lessons learned from the present research have been disseminated to the developers in the hope that the final platform will bring BCI closer to the ultimate goal of a commercial available system for home use.

7. Conclusions

The research aims to develop BCI systems to enhance the user's independence to access services that enable eHealth and eInclusion. Overall the findings from the present evaluation are positive and extremely helpful for the developers to improve the functionality and usability of BCI for users with ABI. The findings indicated that BCI systems can work for people with ABI, which is promising, and that users enjoyed the various applications. The evaluation provides important information to improve the prototype design towards commercially available assistive technology for home use and to enhance the ability of the BCI to improve individuals' functional ability, quality of life and independence.

Acknowledgments

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013, BackHome project grant agreement n° 288566. We would like to thank all of the project partners for their contribution to this research.

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